In Agriculture the changes which have occurred in the period since 1831 have been immense. The last half century has witnessed the introduction of the modern system of subsoil drainage founded on the experiments of Smith of Deanston. The thrashing and drilling machines were the most advanced forms of machinery in use in 1831. Since then there have been introduced the steam-plough; the mowing-machine; the reaping-machine, which not only cuts the corn but binds it into sheaves; while the steam-engine thrashes out the grain and builds the ricks. Science has thus greatly reduced the actual cost of labour, and yet it has increased the wages of the labourer.

It was to the British Association, at Glasgow in 1841, that Baron Liebig first communicated his work "On the Application of Chemistry to Vegetable Physiology," while we have also from time to time received accounts of the persevering and important experiments which Mr. Lawes, with the assistance of Dr. Gilbert, has now carried on for more than forty years at Rothamsted, and which have given so great an impulse to agriculture by directing attention to the principles of cropping, and by leading to the more philosophical application of manures.

I feel that in quitting Section F so soon, I owe an apology to our fellow-workers in that branch of science, but I doubt not that my shortcomings will be more than made up for by the address of their excellent President, Mr. Grant-Duff, whose appointment to the governorship of Madras, while occasioning so sad a loss to his friends, will unquestionably prove a great advantage to India, and materially conduce to the progress of science in that country.

Moreover, several other subjects of much importance, which might have been referred to in connection with these latter Sections, I have already dealt with under their more purely scientific aspect.

Indeed, one very marked feature in modern discovery is the manner in which distinct branches of science have thrown, and are throwing, light on one another. Thus the study of geographical distribution of living beings, to the knowledge of which our late general secretary, Mr. Sclater, has so greatly contributed, has done much to illustrate ancient geography. The existence of high northern forms in the Pyrenees and Alps points to the existence of a period of cold when Arctic species occupied the whole of habitable Europe. Wallace's line—as it has been justly named after that distinguished naturalist—points to the very ancient separation between the Malayan and Australian regions; and the study of corals has thrown light upon the nature and significance of atolls and barrier-reefs.

In studying the antiquity of man, the archæologist has to invoke the aid of the chemist, the geologist, the physicist and the mathematician. The recent progress in astronomy is greatly due to physics and chemistry. In geology the composition of rocks is a question of chemistry; the determination of the boundaries of the different formations falls within the limits of geography; while palæontology is the biology of the past.

And now I must conclude. I fear I ought to apologise to you for keeping you so long, but still more strongly do I wish to express my regret that there are almost innumerable researches of great interest and importance which fall within the last fifty years (many even among those with which our Association has been connected) to which I have found it impossible to refer. Such for instance are, in biology alone, Owen's memorable report on the homologies of the vertebrate skeleton, Carpenter's laborious researches on the microscopic structure of shells, the reports on marine zoology by Allman, Forbes, Jeffreys, Spence Bate, Norman, and others; on Kent's Cavern by Pengelly; those by Duncan on corals; Woodward on crustaceæ; Carruthers, Williamson, and others on fossil botany, and many more. Indeed no one who has not had occasion to study the progress of science throughout its various departments can have any idea how enormous—how unprecedented—the advance has been.

Though it is difficult, indeed impossible, to measure exactly the extent of the influence exercised by this Association, no one can doubt that it has been very considerable. For my own part, I must acknowledge with gratitude how much the interest of my life has been enhanced by the stimulus of our meetings, by the lectures and memoirs to which I have had the advantage of listening, and above all, by the many friendships which I owe to this Association.

Summing up the principal results which have been attained in the last half-century we may mention (over and above the accumulation of facts) the theory of evolution, the antiquity of man, and the far greater antiquity of the world itself; the correlation of physical forces and the conservation of energy; spectrum analysis and its application to celestial physics; the higher algebra and the modern geometry; lastly, the innumerable applications of science to practical life—as, for instance, in photography, the locomotive engine, the electric telegraph, the spectroscope, and most recently the electric light and the telephone.

To science, again, we owe the idea of progress. The ancients, says Bagehot, "had no conception of progress; they did not so much as reject the idea; they did not even entertain it." It is not, I think, now going too far to say that the true test of the civilisation of a nation must be measured by its progress in science. It is often said, however, that great and unexpected as the recent discoveries have been, there are certain ultimate problems which must ever remain unsolved. For my part I would prefer to abstain from laying down any such limitations. When Park asked the Arabs what became of the sun at night, and whether the sun was always the same, or new each day, they replied that such a question was childish, and entirely beyond the reach of human investigation. I have already mentioned that, even as lately as 1842, so high an authority as Comte treated as obviously impossible and hopeless any attempt to determine the chemical composition of the heavenly bodies. Doubtless there are questions, the solution of which we do not as yet see our way even to attempt; nevertheless the experience of the past warns us not to limit the possibilities of the future.

But however this may be, though the progress made has been so rapid, and though no similar period in the world's history has been nearly so prolific of great results, yet, on the other hand, the prospects of the future were never more encouraging. We must not, indeed, shut our eyes to the possibility of failure; the temptation to military ambition; the tendency to over-interference by the State; the spirit of anarchy and socialism; these and other elements of danger may mar the fair prospects of the future. That they will succeed, however, in doing so, I cannot believe. I cannot but feel confident hope that fifty years hence, when perhaps the city of York may renew its hospitable invitation, my successor in this chair—more competent, I trust, than I have been to do justice to so grand a theme—will have to record a series of discoveries even more unexpected and more brilliant than those which I have, I fear so imperfectly, attempted to bring before you this evening. For one great lesson which science teaches is, how little we yet know, and how much we have still to learn.

SECTION B

CHEMICAL SCIENCE

OPENING ADDRESS BY PROF. A. W. WILLIAMSON, PH.D., LL.D., F.R.S., V.P.C.S., PRESIDENT OF THE SECTION

On the Growth of the Atomic Theory

IT has been thought desirable that on the occasion of this half-centenary celebration of the foundation of this great Association, some notice should be presented to the members of what has been doing in the respective branches of science during the period of our activity; and I have, accordingly, traced out for your consideration a very imperfect sketch of the theories which guided chemical inquiry at the beginning of that period, and of the leading changes which have been wrought in them by fifty years' work.

There is perhaps hardly any branch of science which during the last fifty years has made such great and steady progress as chemistry. Let any one compare recent dictionaries of the science (including the bulky supplements, which contain a record of the chief discoveries made while the body of the work was being compiled) with a treatise of chemistry fifty years old. Let him compare a published record of one year's progress of the science fifty years ago with one of modern date. Let him compare, as far as may be possible, the number of men who formerly devoted their whole time and energy to the advancement of chemistry, or who were engaged in industrial pursuits involving a knowledge of the science, with the corresponding number nowadays. Let him count up the services which chemistry had rendered to common life at the commencement of the epoch with those which it has now to show.

Everywhere he will see marvellous evidences of increasing growth. But if he be a reflecting man, he will not be satisfied with wondering at results : he will endeavour to trace them to

their causes, and to discover the guiding principles which have brought them about : he will try to derive, from a knowledge of those guiding principles, a perception of the means by which such progress can best be continued and extended—how it can be most effectively directed to the benefit of his fellow-men.

It is on this aspect of the question that I propose to address you to-day.

The process of scientific investigation includes a great variety of operations, which may be considered under three headings, mental, sensual, and physical. We think, we observe, and we work with our hands. In planning a new experiment we call to mind what is known of the phenomena in question, and form an opinion as to what is likely to happen under conditions somewhat different from those which existed in previous experiments. We regulate by careful observations the necessary manual operations, so as to obtain with accuracy the desired conditions for the new experiment, and we observe attentively the changes which take place in the course of that experiment. The result of such observations is sometimes in accordance with our anticipation, but very frequently at variance with it. If it accords with our anticipation, we put on record the extension which it has given to the application of the general theory on which that anticipation was founded. But if the result is not what we expected, we carefully and critically revise the reasoning which had led us to expect a particular result, and often repeat the same experiment with greater care, or some modification of it.

Materials for a new theory are gained when logically faultless reasoning, checked by accurate observations, have led to results which could not have been foreseen by the aid of any previous theory. When a theory has thus gained a footing in science, it serves as a guide in further work. It guides us in arranging known facts. It guides us to the discovery of new facts. Some times it does these things for a short time only, and is then superseded by some more general theory derived from a wider and more comprehensive view of the facts.

There is, perhaps, nowhere so severe and rigorous a test of the truth of an idea as that which is afforded by its use in any accurate department of experimental science ; and it is worth while, on philosophical grounds, to consider briefly the conditions of growth of the chief chemical theories which have withstood this ordeal and proved themselves to be trustworthy guides in experimental science.

Now as far as I know them, the general theories which have played the chief part in the development of chemistry are mere condensed statements of fact.

Every thoughtful man of science has doubtless indulged in speculations to find the cause of facts which are as yet unexplained ; has imagined some fundamental condition or property of matter which might cause it to produce effects such as are witnessed. It is to be hoped that the time may be far distant when men of science will confine their thoughts within the range of ideas which are proved to be true. But it is most important that they should not confuse such hypothetical speculations with theories which have received experimental verification, and that while employing any theory they should not lose sight of the limits within which it has been proved to be correct, beyond which it can only be used as an hypothesis.

The foundation of the science of chemistry was laid by the discovery of chemical elements ; those distinct varieties of matter which we can neither produce nor destroy. Chemical science treats of those changes of property in matter which can be represented as due to changes of combination of elementary atoms. It knows nothing of the production or destruction of those elementary atoms. Speculations respecting their ultimate form or structure will have found a place in the science as soon as such speculations have helped to arrange the facts which are known, and to discover new chemical facts.

At the commencement of our epoch chemists had classified elements according to their electro-chemical properties. Chemical analysis had established the fact that a good many compounds could be represented as consisting of elementary atoms of two kinds combined in small number. Thus carbonic oxide and carbonic acid had been found to possess respectively a composition which could be represented (adopting our present atomic symbols) by the formulæ CO and CO_2, water by the formula H_2O, marsh gas CH_4, olefiant gas CH_2. The oxides and acids of nitrogen were represented by formulæ corresponding empirically to those which we now adopt. So also ammonia and hydric chloride had their present formulæ. Sulphurous and sulphuric acid had the respective formulæ SO_2 and SO_3. Phos-

phorus and phosphoric acid had the formulæ P_2O_3 and P_2O_5. Baryta and the oxides of iron had the formulæ BaO, FeO, Fe_2O_3.

Such primary compounds were classified upon the same principle which served for the classification of the elements themselves, into electro-positive or basylous and electro-negative or chlorous compounds, and the smallest quantity of each of them, which consistently with an atomic representation of the results of analysis, was deemed capable of existing, was called an atom of that compound.

Very simple compounds possessed of prominent characteristics and distinct reactions had first been isolated and identified. They were found to contain their constituent elements in proportions easily recognisable as multiples of atomic weights. But such simple compounds are rare exceptions among mineral and organic materials, and if the atomic theory could have gone no further than to guide us to an understanding of these few simple compounds, it must soon have given place to some more fundamental conception. It is moreover worthy of notice that in this its most elementary form the atomic theory was not the only conceivable interpretation of the proportions of combination between elements. Those proportions could be as consistently represented by fractions as by integral multiples. Thus, instead of representing carbonic acid as containing twice as much oxygen as is contained in carbonic oxide, we might have represented it as containing the same quantity of oxygen combined with half as much carbon, and using for the moment atomic symbols for a non-atomic theory, we might have written carbonic acid thus $\frac{C}{2}O$. Or we might represent them both by percentage numbers.

It was so simple and natural to adopt the atomic hypothesis, and to represent compounds as built up of atoms, that chemists seem to have paid little attention to any other mode of representing the proportions of combination. They assumed that the variable proportions of elements, which were observed in compounds, were due to the various numbers of elementary atoms respectively aggregated together in each compound. They perceived that the existence of elementary atoms involved the existence of compound atoms, or molecules, as we now call them, and accordingly they represented each known compound of two elements by a molecular formula as simple as possible, consistently with the view of its atomic constitution. Many of these molecules, such as those of the acids, were found to be capable of combining with others of the other class, forming salts, and those combinations were found to take place in proportions corresponding to the weights of the respective molecules, or to very simple multiples of those weights, and the secondary compounds or salts thus formed combined (if at all) in proportions corresponding to simple multiples of their molecular weights. The dualistic representation of the constitution of salts served to represent the results of their analysis consistently with the atomic theory, and a vast number of fundamental facts were collected and arranged by the aid of the dualistic theory of combination.

The actual numbers obtained by analysis of any particular compound exhibited sometimes a very near approximation to those required by an atomatic formula of its composition. Sometimes they differed considerably from those required by theory ; but it was always found that the more pure in substance and the more accurate the analytical operations, the more nearly did the result agree with some atomic formula of the substance.

The compound atoms were units which had grown out of the atomic theory. Each of them was the smallest quantity of a compound, which (consistently with the results of analysis) could be represented as built dualistically of its constituent atoms.

Chemical combination was viewed as a process of juxtaposition, of simple or compound atoms, little account being taken of the disturbance of the previous arrangement of those compound atoms. It was when a constitution, similar to that attributed to salts, was imagined for other compounds not saline in their character, that the dualistic theory broke down. Thus chlorocarbonic acid was represented as a compound of carbonic acid with carbonic chloride, and was accordingly designated as carbonate of carbonic chloride, while the formula was made to contain the formulæ of those bodies. Chlorosulphuric acid and chlorochromic acid were in like manner represented as compounds of sulphuric and chromic acid respectively with imaginary hexachlorides.

Careful investigations of the reactions in which chlorocarbonic acid takes part showed, however, that in each of them it behaves

as a compound containing only two atoms of chlorine. It was found that the commonest and best-known carbonates and sulphates have a fundamentally similar constitution. Thus potassic carbonate may be represented as a compound in which the two atoms of chlorine in phosgene are replaced by two atoms of the radical O K ; and oil of vitriol, as a compound of two atoms of hydroxyl with the same group, S O_2, which in chlorosulphuric acid is combined with two atoms of chlorine. Chlorochromic acid has not been examined to as great an extent as the above compounds, but all we know of it points clearly to its having molecular constitution similar to that of chlorosulphuric acid, viz. Cl_2 Cr O_2, for not only do their vapour-densities agree, but the chromates in their constitution and crystalline forms exhibit a clear analogy to the sulphates.

Moreover, the simpler molecular formulæ, which a fuller knowledge of their chemical behaviour suggested for these bodies, were found in all cases to agree with the volume belonging to the molecule of every pure substance known in the state of vapour.

A difficulty of another kind had been foreseen by the great founder of the dualistic system, and it was by the investigations in organic chemistry that it assumed serious proportions.

Carbon compounds were discovered possessing definite and specific properties, and presenting the characteristics of pure substances, but of which the results of analysis did not agree with any simple proportion between the numbers of their constituent atoms. Their empirical composition could not be decided by the aid of the so-called law of multiple proportions, for two or more atomic formulæ required percentages of the constituents differing so little from one another that analysis could not decide which was the true one.

In order to select the true molecular formulæ of such complex substances from among those which approached most nearly to the results of ultimate analysis, and to determine with certainty their empirical composition, it was necessary to find other methods for the determination of molecular weights. It was necessary to study the various properties of compounds of known composition, and of others which could be prepared in a state of purity ; to determine the vapour densities and rates of diffusion of those which could be obtained in the gaseous state without decomposition ; to determine boiling points and melting points ; to examine crystalline forms of pure compounds and of mixtures ; to determine solubilities and densities of solids and of liquids ; but above all it was necessary to collect fuller and more accurate knowledge of the chemical changes which take place in the mutual reaction of molecules.

A vast amount of accurate and careful work of these kinds has been done, and has been subjected to rigid and often hostile scrutiny during the various steps of its progress. We now know that compound atoms, or molecules as we call them, which can be identified by their geometrical, mechanical, and other properties, are the same as the compound atoms indicated by the most comprehensive chemical evidences of composition and reactions. The molecular constitution of matter was predicted implicitly by the atomic theory of the constitution of the elements ; and, wherever the physical properties of the molecules are such as afford any basis for the determination of their relative weights, such results agree with those derived from purely chemical considerations guided by the atomic theory.

Our knowledge of molecules is as yet in its infancy. Even among the commonest elements and compounds we know the molecular weights of very few, but what we do know of them proves that the idea of compound atoms invented by chemists to explain the elementary facts of chemical action is, as far as it goes, a true representation of what exists in nature.

Many of the molecules thus proved to exist were the same as those suggested under the dualistic system ; but many were proved, by the more accurate and extensive knowledge of their reactions and properties, to have a different weight from that which had been at first attributed to them, yet always consistent with the fundamental requirements of the atomic theory. Thus H_2O, CO, CO_2, CH_4, SO_2, SO_3, CaO, FeO, Fe_2O_3, are the formulæ still used to denote the molecules of the respective compounds, though the last three ought probably to be represented by some multiple. On the other hand, the molecule of olefiant gas is now represented by the formula C_2H_4, instead of CH_2. The chloracetate is $C_2Cl_3HO_2$, instead of C_2Cl_6, C_2O_3, H_2O. The molecule of benzoil chloride is C_7H_5OCl, instead of one corresponding to $(C_7H_5)_2O_3$, $C_7H_5Cl_3$, and chlorosulphuric acid is Cl_2SO_2, instead of $2SO_3$, SCl_6.

In proportion as chemists came to know more of the constitution of molecules, and to study chemical reactions from the point of view of the changes which they bring about in the constitution of molecules, did the idea of substitution come to be more and more used in the place of that of mere additive combination. A vast number of processes of chemical combination, which had been considered as consisting of direct combination, were found to be processes of double decomposition.

One of the most important facts which was brought to light by the careful examination of the composition of salts and organic bodies, aided by the molecular method of representing their constitution, was that hydrogen is chemically one of the metals, and that the compounds formed by the combination of water with acids are analogous to other salts of those acids ; while compounds of hydrogen with elements or radicals like chlorine are salts, analogous in their constitution to other chlorides, &c.

The molecular or unitary mode of viewing the constitution of each substance affords more *true* as well as more simple records of the facts observed in chemical reactions than could be obtained in the dualistic systems. A salt such as hydric sulphate used to be considered as containing sulphuric acid and water, and represented by a formula such as SO_3, H_2O, implying the presence in it of both the substances from which it was known to be formed.

When two elements combined, their product was considered and described as containing the elementary atoms which had served to form it, and it was consistent with this habit to represent a product which had been formed by the combination of two compound molecules as containing those molecules.

But the main business of chemical investigation is to observe accurately the changes of composition which take place in the reactions of known substances, with a view of discovering the atomic changes to which they are due.

The compound formed by the combination of sulphuric acid and water differs in many physical and chemical properties from both of those bodies. Its name and its atomic formula serve to denote the aggregate of properties which are known to belong to it, whereas the dualistic formula, SO_3, H_2O, served to recall the properties of the acid and base from which it was formed, rather than those of the compound itself.

Elementary chemical reactions which according to the binary mode of viewing compounds were supposed to consist of dualistic processes involving sometimes the assumption of forces (like predisposing affinity) of a purely metaphysical character, were now explained as consisting of atomic displacements, or interchanges of a kind well known to be of common occurrence. Thus the evolution of hydrogen by the action of zinc or aqueous hydric sulphate was supposed to be the result of a decomposition of water by the metal, such decomposition being induced by the presence of the acid (SO_3), which exerted a predisposing affinity for the zinc oxide. Our present explanation is a simple statement of the fact, that under the conditions described, zinc displaces hydrogen from its sulphate.

The recognition and study of the metallic functions of hydrogen enabled chemists to obtain far clearer and simpler views of the constitution of salts, and to observe the differences of property which are produced in them by the replacement of one element by another. It enabled us to see more and more clearly the characteristic functions of each element, by comparing the constitution and properties of salts containing it with those of the corresponding salts containing other elements.

Thus in the dualistic system we had for the three common phosphates, PO_4Na_3, PO_4Na_2H, PO_4NaH_2, molecular formulæ in which sodium was represented with twice as great an atomic weight as that which we attribute to it, and which in our atomic weights may be thus represented, viz. P_2O_5, $3Na_2O$; P_2O_5, $2Na$, O ; P_2O_5, Na_2O. In like manner we had such a formula as P_2O_3, $2Na_2O$ (for the phosphite PO_3Na_2H), and for the hypophosphite PO_2NaH_2 we had a formula corresponding to P_2O, Na_2O.

Determinations of water of crystallisation and of chemically combined water proved that many of the compounds assumed on the dualistic system to exist are either not obtainable or have different properties and a different constitution from those which have been described. Thus we now know that the salts PO_4Na_2H, PO_4NaH_2, PO_3Na_2H, and PO_2NaH_2 cannot be deprived of the elements of water without undergoing a fundamental change of composition and of properties.

The atomic weights of the alkali metals and of silver were

found to be half of those of the dualistic system, and an atom of one of these metals, in common double decompositions between their salts and hydrogen-salts, changes place with one atom of hydrogen.

Many products of the combination of known molecules were found to be formed by processes of double decomposition, so that each molecule of such products is built up partly of atoms derived from one of the materials, partly of atoms from the other. Thus potassic hydrate is formed by the combination of a molecule of potash with one 'of water. Yet each molecule of the hydrate is built up of half a molecule of potash and half a molecule of water.

The study of organic compounds played an important part in the improvement of our processes of reasoning. Many of their molecules having a very complex structure were found to undergo in most of their reactions very simple changes, of the same kind as those which mineral compounds undergo. Most of the elements of each organic molecule remained combined together with functions analogous to those of hydrogen or chlorine.

The theory of radicals which had been suggested by the reactions of ammonia-salts and of cyanides was largely extended in organic chemistry.

Many families of organic compounds were discovered, in each of which the members are connected by close analogy of constitution and of properties. Each of these families forms what is called a homologous series, each term of the series being a compound of which the molecule contains one atom of carbon and two atoms of hydrogen more than the previous term.

Thus a series of compounds was proved to have reactions similar to those of common alcohol, and molecular weights ranging from 32 to 438. The lower terms of the series are distinguished from one another by differences of boiling points approximately proportional to the number of atoms of carbon and hydrogen by which they differ from one another; whilst the higher terms undergo decomposition at the higher temperatures required for their evaporation, and are distinguished from one another by differences of melting points, that of the alcohol $C_{30}H_{62}O$ being about 85° C. In their constitution these alcohols were found to be analogous to the alkaline hydrates.

In like manner various other series of alcohols were discovered corresponding respectively in their constitutions to other classes of metallic hydrates. Series were also found of which the members present analogies of reaction with monobasic, bibasic, tribasic hydrogen salts respectively.

These and many other such discoveries were made under the guidance of the atomic theory, developed to the point of systematically recognising and studying the mutual reaction of molecules.

One of the most remarkable and important extensions which our knowledge of molecules has undergone consisted in the discovery that various elements in what we are accustomed to consider the free state, really consist of molecules containing like atoms combined with one another.

Thus chemists adopt the formulæ O_2, H_2, Cl_2, P_4, J_2, As_4, to denote molecules of the respective elements, and we have for these molecular formulæ evidences of the same kinds as those which serve to establish the molecular formulæ ClH, H_2O, NH_3, &c. In all the best-known reactions in which chlorine or hydrogen are either taken up or evolved we find that those elements behave as chemical compounds of two like atoms; and, moreover, their molecules, as determined from a study of their reactions, have the same volume as that of every compound molecule proved to evaporate without decomposition.

With this knowledge of the molecular constitution of hydrogen and of chlorine gases, we come to regard the direct formation of hydric chloride as due to a process of double decomposition between two molecules, like the reaction of chlorine on an equal volume of marsh gas.

Many other reactions, such as the evolution of hydrogen by the action of zinc on a hydrogen salt, the liberation of chlorine and nitrogen on the explosive decomposition of their compound, the direct combination of oxygen and hydrogen, we may expect to be able to resolve into mere processes of double decomposition.

The earliest determinations of combining proportions were made with salts (hydrogen salts and others) which undergo double decomposition by mutual contact, and the term equivalent was subsequently introduced to indicate the proportional weights of analogous substances found to be of equal value in their chemical effects. Tables of equivalent weights of acids consisted of numbers standing to one another in the same proportions as the weights of the respective substances found to be of equal value in neutralising a fixed quantity of a particular base; and in like manner tables of the equivalent weights of bases recorded the proportions by weight in which certain bases might replace one another in the neutralisation of a particular quantity of a given acid. Similar determinations have been tabulated of the so-called equivalent weights of elements. Under the dualistic system chemists paid little attention to the essential difference between atomic weights and equivalent weights; and some were of opinion that the facts of chemistry might be represented as consistently from the point of view of equivalence as from that of atoms, and that the idea of atoms (which they considered to be hypothetical) might be dispensed with.

In the system of atomic weights employed under that system, two atoms of hydrogen were generally represented as reacting together, and the symbol of the double atom was marked thus,

Ħ. The alkali metals and silver were represented as having atomic weights twice as great as those which we now adopt, and equivalent to those of the magnesian metals and of oxygen. In a great number of the common reactions of these elements the atomic symbols were consistently used as equivalent symbols. But those who professed to dispense with the atomic theory used atomic symbols, even in cases where they did not represent equivalent weights. Thus nitrogen was always represented by its atomic symbol, and the composition and reactions of nitrogen compounds were always studied and represented in accordance with the atomic theory, using various multiple proportions of what they were still pleased to call equivalent weights, using molecular weights, and various other ideas which formed part of the atomic theory, and which had no known connection with the notion of fixed equivalence. If, however, it be true that all chemical compounds consist of elementary atoms, and that the explanation of chemical reactions consists in stating more and more precisely the changes of combination between the constituent atoms of the reacting molecules; equivalence could only be said to exist between a like number of atoms when they were known to have similar functions. It became necessary to study the relation of equivalence between elementary atoms, instead of studying them from the point of view of elements divisible in any proportion.

It is worth while noticing the general process by which this intellectual change was brought about; for there is a good deal yet to be done in the matter, and our future progress may be guided by experience gained in the past.

It was essentially one-sided. One consideration was brought into very prominent relief, and it threw a marvellous light on the matter. It gave us a clear view of the natural order among elements; but, like every other strong light, it fell on one side only.

The equality of vapour-volumes had been used with great advantage in conjunction with chemical reactions and other evidence as a characteristic of molecules, and the attention of chemists was greatly arrested by the consideration of four typical compounds, which upon the concurrent evidence of very extensive chemical examination and equality of vapour-volumes were known to have respectively a composition corresponding to the formulæ ClH, OH_2, NH_3, CH_4.

It was known that the atom of oxygen in water can be replaced by chlorine, but that two atoms of chlorine are needed for the purpose. The atom of nitrogen in ammonia requires three atoms of chlorine to replace it, whilst in marsh gas the atom of carbon is replaceable by four atoms of chlorine. Other elements were studied from the point of view of their respective resemblance to these, and arranged in classes, each of which consisted of atoms equivalent to one another. Thus chlorine, bromine, iodine, fluorine, hydrogen, potassium, sodium, lithium, silver, &c., constituted a class of atoms of equal value, and were called monads. Oxygen, sulphur, selenium, tellurium, calcium, strontium, barium, magnesium, zinc, cadmium, mercury, lead, copper, &c., were classed together as dyads, having equal value amongst themselves, but double the atomic value of the members of the first class. So nitrogen, phosphorus, arsenic, antimony, bismuth, with boron, and some other elements, were considered as forming a class of atoms each of which has three times the value of the monads. The class of tetrads contained carbon, silicon, tin, platinum, &c.

Many apparent exceptions to these atomic values were satisfactorily explained as due to the partial combination of like

atoms with one another. Thus in the vast majority of hydro-carbons, such as C_2H_6, C_2H_4, C_2H_2, &c., the atoms of carbon do not appear to be tetravalent, inasmuch as each of the molecules contains less than four atoms of hydrogen to every one atom of carbon. It was well known, however, that polyvalent atoms can combine partly with one element, partly with another, and also that like atoms can combine with one another. Why then should not two tetravalent atoms like carbon combine respectively with three atoms of a monad, and also combine with one another? The compound must be a single molecule with the properties known to belong to methyle C_2H_6. Again, if this molecule were deprived of two of its atoms of hydrogen, each of the atoms of carbon must combine further with the other atom of carbon forming H_2CCH_2; and a further step in this same direction would give us acetylene HCCH, in which each atom of carbon is combined with the other to the extent of three quarters of its value, and with one atom of hydrogen. An extension of this reasoning led to the discovery of long chains of atoms of carbon, each atom forming a link, and each of them (short of the ends) being combined with two other atoms of carbon, while its saturation is completed by hydrogen.

Similar partial combinations of like atoms with one another were recognised in many other classes of compounds, and there is strong reason to expect that the application of the principle will be far more widely extended in proportion as our knowledge of the silicates and other complex classes of compounds becomes somewhat definite.

This incorporation of the doctrine of equivalence into the atomic theory by the division of the elements into classes consisting respectively of equivalent atoms, was probably one of the most important general steps as yet made in the development of the atomic theory. It was seen to correspond in so clear and striking a manner with a vast number of well-known properties and reactions of compounds as to deserve and acquire the confident trust of chemists. But, as often happens in such cases, this confidence in the result carried many of them too far. It led them to assume that atomic values in all other chemical compounds must be always the same as in the compounds under consideration. They saw that they had got hold of the truth, and they thought it was the whole truth. For instance, one most distinguished chemist assumed that each elementary atom has only one value in its compounds; that the atom of nitrogen has always the value three, as in ammonia and its products of substitution, and that in sal ammoniac the atom of nitrogen is chemically combined only with three atoms of hydrogen, whilst the molecule of ammonia is in a state of molecular combination with hydric chloride. Another most distinguished chemist admitted that nitrogen and phosphorus have two atomic values, but not more than two. He held that the respective combining powers are always satisfied by the same number of atoms, no matter what the character of the uniting atoms may be.

With respect to these views it may be noticed that the assumption of combination between molecules as due to some other force than that which binds together the constituents of each molecule—in fact the assumption of molecular combination as an unknown something different from chemical combination, is open to even more grave objections than those which led us to abandon the dualistic system.

To represent a molecule of sal ammoniac as a compound containing two molecules, each one built up by the chemical combination of the constituent atoms, and the two united together by some other force called molecular, was hardly a step in advance of the view which represented it as containing two molecules united together by the same kind of force as that which holds together the atoms in each of the constituent molecules.

The other form of the theory of atomicity as an inherent property of each atom enabling it to combine with an equal number of other atoms, whatever the character of those other atoms may be, seems difficult to reconcile with such facts as the following :—An atom of nitrogen is not known to combine with more than three atoms of hydrogen alone, or of substances like hydrogen, but it forms stable compounds with five atoms (as in the ammonia salts), when four of them are basylous and one of them is chlorous. An atom of sulphur is not known to combine with more than two atoms of hydrogen alone, but it forms stable compounds with four atoms, if three of them are like hydrogen, while the fourth is chlorous. Instances like these are plentiful, and they lead us to look to the chemical characters of the atoms bound together in one molecule as a fundamental condition of the atomic value of the element which binds them together.

Theoretical limitations of natural forces are very difficult of proof, and it is well to be slow and cautious in adopting any such limitation.

A careful consideration of the facts of the case has led me not only to doubt the validity of the supposed limits of atomic value, but to doubt whether we have grounds for assigning any limits whatever to such values.

Atomic values appear to me to be in their very nature variable quantities, and I venture to think that chemistry will be greatly advanced by a full and careful study of the conditions of variation of atomic values.

Two conditions of change of atomic value are particularly worthy of notice :—

I. Temperature.
II. The chemical character of the uniting atoms.

Atomic values increase with fall of temperature, and diminish with rise of temperature. An atom which is combined with as many basylous monads as it can take up by themselves, will take up chlorous monads, or both chlorous and basylous, and reciprocally.

In illustration of the diminution of atomic values with rise of temperature, I may adduce the following well-known reactions : Sal ammoniac containing nitrogen combined with five monads breaks up at a high temperature into ammonia and hydric chloride; and in like manner other ammonia salts decompose by heat forming ammonia or an amide, with trivalent nitrogen. The highest chlorides of phosphorus and of antimony are decomposed by heat into free chlorine and the lower chloride. Potassic fluosilicate is decomposed by heat into silicic and potassic fluorides ; and carbonic acid breaks up at high temperatures into a mixture of carbonic oxide and oxygen.
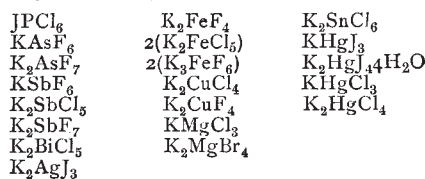
Amongst illustrations of the greater atomic values which elements assume by combining with both chlorous and basylous atoms than with atoms of the one kind only, we may take the following cases : platinum is a metal of which the atom has been supposed to be always tetravalent, because it has not been found capable of combining with more than four atoms of chlorine. The common solution formed by aqua regia contains the compound H_2PtCl_6, a perfectly definite and crystallisable hydrogen salt. Chemists are constantly making and using the potassium and ammonium salts, &c., corresponding to it, yet they conceal from themselves the fact that the atom of platinum is directly combined with eight monads by calling the compounds double salts. The atom of silicon in the silico-fluorides such as H_2SiF_6, or K_2SiF_6, is combined with twice as many monads as it can take up of one kind ; so boron in the crystalline salt $NaBF_4$ has a higher atomic value than in its fluoride, owing to the presence of the atom of sodium.

In like manner the atom of gold in the well-known salt $NaAuCl_4$, has a higher value than it can assume with chlorine alone.

Sulphur, of which the atom does not combine with more than 2 atoms of hydrogen, forms with 3 atoms of methyle, or ethyle, and 1 atom of iodine, or chlorine, &c., the well-known compounds like $JSMe_3$; and iodine, which is considered a monad, forms the crystalline and stable periodate $OJ(OH)_5$ and the various metallic derivatives, such as

$$OJ \, ONa \qquad OJ \, (ONa)_2 \qquad OJ \, (OAg)_5$$
$$(OH)_4 \qquad\quad (OH)_3$$
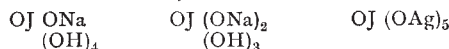
The crystalline compound of the perchlorate with water $(HClO_4 2H_2O)$ has probably a similar constitution. Chemical journals abound with descriptions of definite and well-characterised compounds, which have, like the above, been put aside by the atomicity theory, as mere molecular compounds. The following formulæ are taken almost at random, in illustration of the generality of atomic values far beyond those acknowledged by the theory of atomicity.

$JPCl_6$	K_2FeF_4	K_2SnCl_6
$KAsF_6$	$2(K_2FeCl_5)$	$KHgJ_3$
K_2AsF_7	$2(K_3FeF_6)$	$K_2HgJ_4 4H_2O$
$KSbF_6$	K_2CuCl_4	$KHgCl_3$
K_2SbCl_5	K_2CuF_4	K_2HgCl_4
K_2SbF_7	$KMgCl_3$	
K_2BiCl_5	K_2MgBr_4	
K_2AgJ_3		

I have for convenience written in the middle of each of these

formulæ the symbol of the atom which I assume to act as connecting element. If we consider the atomic values usually found in these elements, together with those represented by the above list, we see that their atomic values vary according to the numbers given in a line with them respectively in the following table. It has yet to be proved that the atom of platinum is tetravalent in any known compound, for there is no sufficient evidence to show that platinic chloride has a molecular weight corresponding to the formula $PtCl_4$, instead of one corresponding to Pt_2Cl_8, each atom of platinum being partly combined with the other, partly with chlorine.

Atomic Symbols.							Atomic Values.
C	...	...	...	...	...	...	2, 4
S	...	...	...	...	...	...	2, 4
Pt	...	...	...	...	...	...	4 (?), 8
Si	...	...	...	...	...	...	4, 8
Sn	...	...	...	...	...	...	4, 8
Cu	...	...	...	...	...	...	2, 6
Hg	...	...	...	...	...	...	2, 4, 6
Mg	...	...	...	...	...	...	2, 4, 6
Ag	...	...	...	...	...	...	1, 5
B	...	...	...	...	...	...	3, 5
J	...	...	...	...	...	...	1, 7
N	...	...	...	...	...	...	3, 5
P	...	...	...	...	...	...	3, 5, 7
As	...	...	...	...	...	...	3, 7, 9
Sb	...	...	...	...	...	...	3, 5, 7, 9
Bi	...	...	...	...	...	...	3, 7
Au	...	...	...	...	...	...	3 (?), 5

Not only are there elements of which an atom is found in combination with a greater number of basylous and chlorous monads together than of either kind alone, but there are also elements which are not known to form chemical compounds with hydrogen or potassium alone, and yet which combine with either of them when also combined with chlorine, fluorine, &c. This is illustrated by the following compounds, viz., $HAuCl_4$, H_2PtCl_6, $NaBF_4$, K_2SiF_6, K_2FeF_4, K_2CuCl_4. It is also well known that there are many cases of elements of which an atom cannot combine with as many monads of one kind as of another. For instance an atom of nitrogen or of antimony is only known to be trivalent in combination with hydrogen; but each of them occurs in the form of a pentavalent compound with chlorine. Antimony forms either no compound with five atoms of bromine, or a compound more unstable than the higher chloride.

Many more such instances might easily now be given, and a vast number will doubtless be found when the investigations of chemists are directed to the search for them. I have only given these few by way of illustration of the leading conditions of change of atomic values.

In the course of their investigations of the precise interchanges of atoms which take place between molecules, chemists were frequently led to observe evidences of the order in which the constituent elements are combined; and with the more wide and accurate knowledge of reactions which is now in their possession, they have been enabled to follow up so far the study of the respective state of combination of each atom in a molecule as to arrive at simple and consistent explanations of facts which had previously eluded the grasp of science.

Our knowledge of the order of combination of atoms in a molecule and of the differences between direct and indirect combinations of particular atoms may be said to have originated chiefly in the study of the compounds of nitrogen. Thus it was found that the hydrogen in ammonia differs in many of its chemical functions from hydrogen in hydrocarbons. A base (called methylia) was discovered having a molecular composition corresponding to the empirical formula (CNH_5), and this base was found to contain two atoms of hydrogen like those of ammonia, and three atoms like those in hydrocarbons. Its constitution was accordingly represented by a formula describing it as an ammonia, in which one atom of hydrogen is replaced by the monad methyle, or, to be more explicit, as containing two atoms of hydrogen directly combined with nitrogen, and three atoms of hydrogen indirectly combined with that same atom of nitrogen through the intervening atom of carbon. Writing in juxtaposition to one another the symbols of those atoms which are directly combined, we can express the facts by the following formula, viz. H_2NCH_3.

Those marvellous varieties of matter called isomeric compounds found their natural explanation in differences of the respective arrangements of like atoms. Thus two bases were

discovered having the same empirical molecular formula C_2NH_7. One of them is made by different reactions from the other, and in its decompositions differs from the other. All these chemical differences between them are found to be due to the fact that one of them (called ethylia) contains two atoms of hydrogen directly combined with the nitrogen, and the monovalent hydrocarbon ethyle in place of the third atom of hydrogen; whilst the other (called dimethylia) contains only one atom of hydrogen combined directly with nitrogen, the carbon of the two atoms of methyle completing the saturation of the trivalent nitrogen, as expressed by the formula $HN(CH_3)_2$.

It was subsequently proved that an atom of oxygen may combine with two like or unlike monads, such monads being indirectly combined with one another through the intervening atom of oxygen. Thus five of the atoms of hydrogen in common alcohol were proved to be in direct combination with the carbon, whilst the other one is indirectly combined with it through the oxygen, as expressed by the formula $HO(C_2H_5)$.

Another compound (called methyl-oxide) was proved to have the same empirical composition, but very different proporties and reactions, its constitution being explained by the formula H_3COCH_3.

Again, two compounds of distinct reactions and properties were found to have the same empirical molecular composition, C_2NH_3, and it was clearly proved that in one of them the two atoms of carbon are directly combined thus, $NCCH_3$, whilst in the other they are indirectly combined through the atom of nitrogen $CNCH_3$.

An immense amount of admirable work has been done of late years (especially in Germany) in working out the evidences of the atomic order of complex organic bodies, and in thereby obtaining a command of their reactions.

Evidences of the same kind have been obtained of the atomic arrangement of some few of the simplest inorganic bodies, and it is to be hoped that ere long chemists will recognise the importance of examining the constitution of salts with the aid of the principles established in organic chemistry.

The foundation is already laid by our knowledge of the constitution of such compounds as

$$HOH,\ HOK,\ HONH_4,\ HONO_2$$
$$HOPbOH,\ HOPbONO_2,\ HOCOK,\ HOSOH$$
$$\qquad\qquad\qquad O \qquad\qquad O_2$$

and there is a strong probability regarding the atomic constitution of many other water compounds, *e.g.*

$$SO_4H_2 + H_2O = OS(OH_2)_4,\ SO_5H_4 + H_2O = S(OH)_6.$$
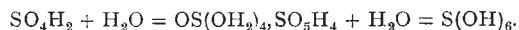
Amongst the extensions of our means of examining the physical properties of matter, and thereby discovering new varieties of matter for chemical investigation, spectrum analysis has played an important part, and is no doubt destined to do far more. It has already led chemists to the discovery of several previously unknown elements, and has led to the detection of various known elements in distant masses of which we had previously no chemical knowledge.

Up to this point the growth of the atomic theory will be seen, from the general outline which I have endeavoured to trace, to have consisted mainly in the more and more full and exact identification of each elementary atom, and in the accumulation of more and more varied and accurate evidences of its functions in relation to other atoms. A step was made towards a knowledge of the general relations of atoms to one another by their preliminary classification according to their best-known values.

But a far greater step has been more recently made, one which is evidently destined to lead to most important results.

It was discovered that if we arrange the elements in the empirical order of their respective atomic weights, beginning with hydrogen and proceeding thence step by step to the heaviest atom, we have before us a natural series with periodically ecurrent changes in the chemical and physical functions of its members.

Of course the series is imperfect, and exhibits gaps and irregularities; but what view of natural order was complete in its infancy?

Some of the gaps have already been filled up by the discovery of elements possessing the anticipated properties. The generalisation affords a brilliant addition to the previous corroborations of the reality of the units of matter which chemists have discovered.

Chemists have as yet taken but little account of atomic motion;

although the most perfect explanation of a chemical reaction consists of a statement of the atomic interchange which takes place between two molecules ; or the change of mutual combination between the atoms in one molecule.

It has, however, been proved that the heat of combination affords a measure of its force ; and we know that in giving off heat particles of matter undergo a diminution of velocity of motion. We see, accordingly, that substances capable of exerting great force by their combination are those which can undergo a great diminution of the velocity of their internal motions, and reciprocally.

The force of chemical combination is evidently a function of atomic motion.

It has been shown that the relative velocities of certain atomic interchanges afford a measure of the amount of chemical action between two substances ; but a vast amount of work will doubtless be required to develop the atomic theory to the point of explaining the force of chemical action in precise terms of atomic motion.

The general terms of chemistry are mere symbols. Each of them serves to recall a group (usually a very large group) of facts established by observation. The explanation of each term is afforded by a careful study of the facts which it is used to denote ; and, accordingly, a chain of evidence involving the use of chemical terms can be fully understood only by chemists accustomed to the consideration of such evidence. The general outline of it may perhaps be to some general thinkers of sufficient interest to attract them to further study of our science.

SECTION C

GEOLOGY

OPENING ADDRESS BY A. C. RAMSAY, LL.D., F.R.S., &C., &C., DIRECTOR-GENERAL OF THE GEOLOGICAL SURVEY, PRESIDENT OF THE SECTION

On the Origin and Progress of the Present State of British Geology, Especially since the first Meeting of the British Association at York in 1831

IN the year 1788 Hutton published his first sketch of his "Theory of the Earth," afterwards extended and explained by Playfair in a manner more popular and perspicuous than is done in Hutton's own writings. In this grand work, Hutton clearly explains that the oldest known strata, like their successors, are derivative, and that as far as *observation* can discover, in all geological time, "we find no vestige of a beginning, and no sign of an end." The complement to this far-seeing observation was at length brought about by William Smith, in his original "Geological Map of the Strata of England and Wales" in 1815, followed, in 1816, by his "Strata Identified by Organised Fossils." This great discovery, for such it was, threw a new light on the history of the earth, proving what had before been unknown, that all the "Secondary" formations, at least from the Lias to the Chalk inclusive, contained each a set of distinctive fossils by which it could be recognised. A law was thus provided for the identification of formations which geographically are often widely separated from each other, not only in England in the case of minor outliers, but also easily applicable to great areas on the neighbouring continent of Europe.

In 1811 the first volume of the *Transactions* of the Geological Society was published, and in 1826-27 there appeared the first volume of the *Proceedings*, the object being to communicate to the Fellows as promptly as possible the *Proceedings* of the Society "during the intervals between the appearance of the several parts of the *Transactions*." The last volume of the *Transactions* contains memoirs read between the years 1845-1856, and only four volumes of the *Proceedings* appeared between the years 1826 and 1845 inclusive, after which the title of the annual volume was changed to that of the "Quarterly Journal of the Geological Society." The Geological Society, to which the science owes so much, was therefore in full action when the British Association was founded in 1831, and the memoirs read before the Society from 1831 to this date may be said to show generally the state of British geology during the last fifty years. To this must be added the powerful influence of the first (1830) and later editions of Lyell's "Principles of Geology," a work which helped to lay the foundations of those researches in Physical Geology which both in earlier and later years have attracted so much attention.

Fifty years ago, in this city, Viscount Milton was president of the first meeting of "The British Association for the Advancement of Science," which he explained had for its chief object "to give a stronger impulse and more systematic direction to scientific inquiry." In his address he pointed out the numbers of Philosophical Societies which had by degrees sprung up in all parts of the kingdom ; and the practicability, through the means of the Association, "including all the scientific strength of Great Britain," "to point out the lines in which the direction of science should move."

In that year, 1831, Prof. Sedgwick was president of the Geological Society, and the Geological and Geographical Committee of the British Association recommended that geologists should examine the truth of that part of the theory of Elie de Beaumont, in its application to England, Scotland, and Ireland, which asserts that *the lines of disturbance of the strata assignable to the same age are parallel ;* that Prof. Phillips be requested to draw up *a systematic catalogue of all the organised fossils of Great Britain and Ireland ;* and that Mr. Robert Stephenson, civil engineer, be requested to prepare a report upon *the waste and extension of the land on the east coast of Britain, and the question of the permanence of the relative level of the sea and land.*

In 1881 it seems strange to us that, in 1831, with William Smith's map of "The Strata of England and Wales, with part Scotland," before them, it should have been considered necessary to institute an inquiry as to the truth of the general parallelism of disturbed strata, which, in a limited area like England, had suffered upheaval at different successive epochs ; and we may fancy the internal smile with which Phillips, the nephew of Smith, regarded the needless proposal. The masterpiece of the old land-surveyor and civil engineer remains to this day the foundation of all subsequent geological maps of England and Wales ; and *as an unaided effort of practical genius*—for such it was—it seems impossible that it should be surpassed, in spite of all the accuracy and detail which happily modern science has introduced into modern geological maps.

The first paper read at York, in the year 1831, was by Prof. Sedgwick, "On the General Structure of the Lake Mountains of the North of England." This was followed by "Supplementary Observations on the Structure of the Austrian and Bavarian Alps," by the Secretary of the Society, Mr. Murchison, a memoir at that time of the highest value, and still valuable both in a stratigraphical point of view and also for the light which it threw on the nature of the disturbances that originated the Alpine mountains, and their relations in point of date to the far more ancient mountains of Bohemia. In his elaborate address in the same year, on his retiring from the president's chair, he largely expatiates on the parallelism of many of the great lines of disturbance of what were then distinguished as the more ancient *schistose* and *greywacké* mountains, and quotes the authority of Elie de Beaumont for the statement, "that mountain chains elevated at the same period of time have a general parallelism in the bearing of their component strata." On a great scale this undoubtedly holds true, as, for example, in the case of the Scandinavian chain, and the more ancient Palæozoic rocks north of Scotland, Cumberland, and even of great part of Wales. The same holds good with regard to the parallelism of the much more recent mountain ranges of the Apennines, the Alps, the Caucasus, the Atlas, and the Himalayas, all of which strike more or less east and west, and are to a great extent of post-Eocene, and even partly of post-Miocene age. The same, however, is not precisely the case with the Apalachian chain and the Rocky Mountains of North America, the first of which trends N.N.W., and the latter N.N.E. The remarkable chain of the Ural Mountains trends nearly true north and south, and is parallel to no other chain that I know of, unless it be the Andes and the mountains of Japan. It is worthy of notice that the chain of the Ural is of pre-Permian age according to Murchison, while Darwin has shown that the chief upheaval of the Andes took place in post-Cretaceous times.

The Apalachian chain is chiefly of post-Carboniferous date, and the Rocky Mountains have been re-disturbed and re-elevated as late as post-Miocene times.

In the same address Prof. Sedgwick entered an eloquent protest against the broad uniformitarian views so powerfully advocated in the first edition of Lyell's "Principles of Geology" in 1830, in which, throwing aside all discussion concerning cosmogony, he took the world as he found it, and, agreeing with Hutton that geology is in no way concerned with, and not sufficiently